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A NEW INTERPRATATION OF THE ORIGIN OF THE WADATI-BENIOFF ZONES IN THE MEDITERRANEAN REGION

Abstract. Because of the close similarity of some Italian and Mediterranean tectonic situations to the East Asia tectonics – arcs, trenches, Wadati-Benioff zones, volcanic and seismic activities, and a typical horizontal bending of the alleged lithospheric slab –, many clues are examined in search of new interpretations of the Mediterranean geological and observational evidence, with the aim of finding solutions that are exportable to the problems of the circumpacific arc-trench zones. The facts coming from surface geology, magmatism, geochemistry, different method tomographies, etc., are at variance with the alleged Africa-Eurasia convergence. The clues for rifting prevail over those for compression, and many tectonic situations previously interpreted as due to plate collisions, are associated or mixed to rifting evidence. The proposal is put forward that uprising of mantle material wedges between two separating lithospheric plates could be a new working hypothesis. On an expanding Earth the region interposed between Eurasia and Africa has always had a smaller latitudinal extension with respect to the large Paleo Tethys and Neo Tethys appearing on constant-radius paleogeographical reconstructions. It is then possible, in the expanding Earth view, also to identify as phases of opening the Paleo Tethys and Neo Tethys currently alleged ‘closure’, which has added to the Proterozoic nuclei the Variscan and Alpine terranes respectively. These phases and their orogens have to be considered as extensional phases, and the added terranes of African provenance (e.g. the Adriatic fragment) should be regarded as fragments left behind as continental Africa moved away. In this sense, considering the ongoing process of opening as having Proterozoic origin, it is possible to speak of the Mediterranean as a slowly nascent ocean, but also – paradoxically – as a very old ocean.

UNA NUOVA INTERPRETAZIONE PER L’ORIGINE DELLE ZONE DI WADATI-BENIOFF NELLA REGIONE MEDITERRANEA

Riassunto. Recenti rassegne dei risultati di gruppi di lavoro su tomografie sismiche a grande scala hanno mostrato che il prolungamento verso il confine nucleo-mantello della litosfera in subduzione, così come previsto dalla plate tectonics, non è chiaramente identificabile. Anzi, molto spesso nelle immagini tomografiche il corpo ad alta velocità diventa orizzontale all’altezza e all’interno della zona di transizione tra mantello superiore e inferiore (a profondità tra 450 e 650 km) per poi a volte mostrare una tendenza a ripiegarsi dolcemente ancora verso il mantello superiore. Questa ormai riconosciuta difficoltà meccanica, richiede una reinterpretazione delle zone di fossa, arco e retroarco. Questo obiettivo può essere perseguito con studi della nostra regione Mediterranea, considerando che molte caratteristiche tettoniche dell’Asia orientale – archi fosse, zone di Wadati-Benioff, attività sismica e vulcanica, orizzontalità dello slab litosferico alla zona di tranzizione, ecc. – sono presenti anche nella nostra regione. Si sono quindi esaminati indizi di provenienza diversa con lo scopo di trovare nuove soluzioni interpretative che siano esportabili alla regione circumpacifica. Si è trovato che fatti provenienti dalla geologia, geomorfologia, magmatismo, geochimica, tecniche tomografiche, ecc., sono in conflitto con la presunta convergenza tra Africa ed Eurasia. Gli indizi di rifting prevalgono su quelli di compressione, e molte situazioni tettoniche precedentemente interpretate come causate da collisione tra placche sono associate ad evidenze tensionali. I corpi ad alta velocità che caratterizzano le zone di Wadati-Benioff si connettono con continuità con una grande giacitura di mantello a velocità anomalmente alta intrappolato nella zona di transizione al di sotto di gran parte della regione Mediterranea settentrionale. Questa situazione può essere più convenientemente interpretata come una risalita di lembi di mantello – guidati dalla isostasia – nel mezzo di due placche litosferiche in mutuo allontanamento. Questo nuovo schema regionale può essere messo in relazione con quello globale della Terra in espansione, nel quale, dal Proterozoico al Mesozoico, la regione interposta tra Africa ed Eurasia deve sempre aver avuto una limitata estensione in latitudine rispetto ai troppo larghi oceani Paleo Tetide e Neo Tetide che appaiono su ricostruzioni paleogeografiche eseguite a raggio terrestre costante. È quindi possibile, ragionando nello schema della espansione terrestre, identificare

le fasi correntemente considerate di chiusura delle successive Tetidi, come fasi di progressiva apertura, le quali hanno aggiunto al nucleo Proterozoico i terreni Caledoniani, Varischi ed Alpini. Queste fasi ed i loro orogeni, dovrebbero essere considerati come fasi estensionali, ed i terreni di provenienza Africana (quale ad esempio il frammento Adriatico) dovrebbero essere individuati come frammenti lasciati indietro durante il moto di allontanamento dell'Africa continentale. In questo senso, se il processo di pulsante apertura ha avuto origine almeno nel Proterozoico, è possibile parlare del Mediterraneo come di un oceano in lenta nascita, ma anche, paradossalmente, di un oceano molto antico.

EVIDENCE FROM SURFACE AND FROM DEPTH

All the available macroseismic data of Italy (essentially the isoseismal maps) was used (Boschi et al. 1995, Scalera, 1997) to produce both the Map of Maximum felt Effects in Italy and the couple of maps of the Number of VII and VIII MCS degree felt effects in Italy. While the Map of the Number of VIII MCS provides an immediate perception of the areas more frequently shocked to a very dangerous level of damaging, the Map of the Number of VII MCS could have an interest as tectonic index. On this last map, the maximum occurrence of VII degree MCS areas is distributed along the Apennine belt on two parallel narrow lines which are perceptible from Northern to Southern Apennines (Fig. 1).

A possible interpretation of this rail-like pattern of the seven degree seismicity is that these two parallel lines could represent a boundary of a inner zone – a narrow summital belt – that is moving, collapsing, with respect to the region external to the two lines. Other clues seem in favour of this interpretation: The focal mechanisms of the stronger earthquakes on Adria peninsula are indicative of normal faults on the axis of the orogen, and of compressive stress on the Adriatic front, on the eastern Apennines slope. Few strong earthquakes are expressed on the volcanic zone on the western slope. The same Indication of a tensional state of the central summital belt of Apennines come from the analysis of in-situ stress data, the borehole breakouts in deep wells (Montone et al., 1997). A further detailed seismo-geodetic investigation of the recent Colfiorito's earthquakes (1997-1998, M > 5) has revealed that the succession of tensional main shocks of the sequence has produced a subsidence of the epicentral region of several centimetres (Salvi et al., 1997; Barchi et al., 2003).

Deep tomographic images have been recently published for the Italian region (Cimini, 1999; Amato and Cimini, 2001; Cimini and Gori, 2001; Lucente et al. 1999; Di Stefano et al., 1999; Neri et al., 2002; Montuori, 2004). In a P wave 3-D deep velocity image (Cimini, 1999), using teleseismic events, is evident a deep elongated belt of higher velocity starting from under the crust in correspondence of the Calabrian arc axis and dipping at high angle – or nearly vertically – toward the Tyrrhenian sea. The plotting of the hypocenters of the deep regional seismicity shows that the pattern of the Benioff focal zone – up to 400 km depth – is not in correspondence with the northern interface between the alleged subducing slab revealed in the tomography and the depth of the backarc basin, but it is in a somewhat not-correlated position with respect to the central axis of the high-velocity structure. The same kind of teleseismic waveform were collected to determine a 3-D velocity structure beneath the central-southern Apennines (Cimini and Gori, 2001), and a similar narrow high velocity structure is found dipping at near 45° towards the basin centre, but no seismicity deeper than 50 km is present in this region (Di Stefano et al., 1999; Lucente et al.1999).

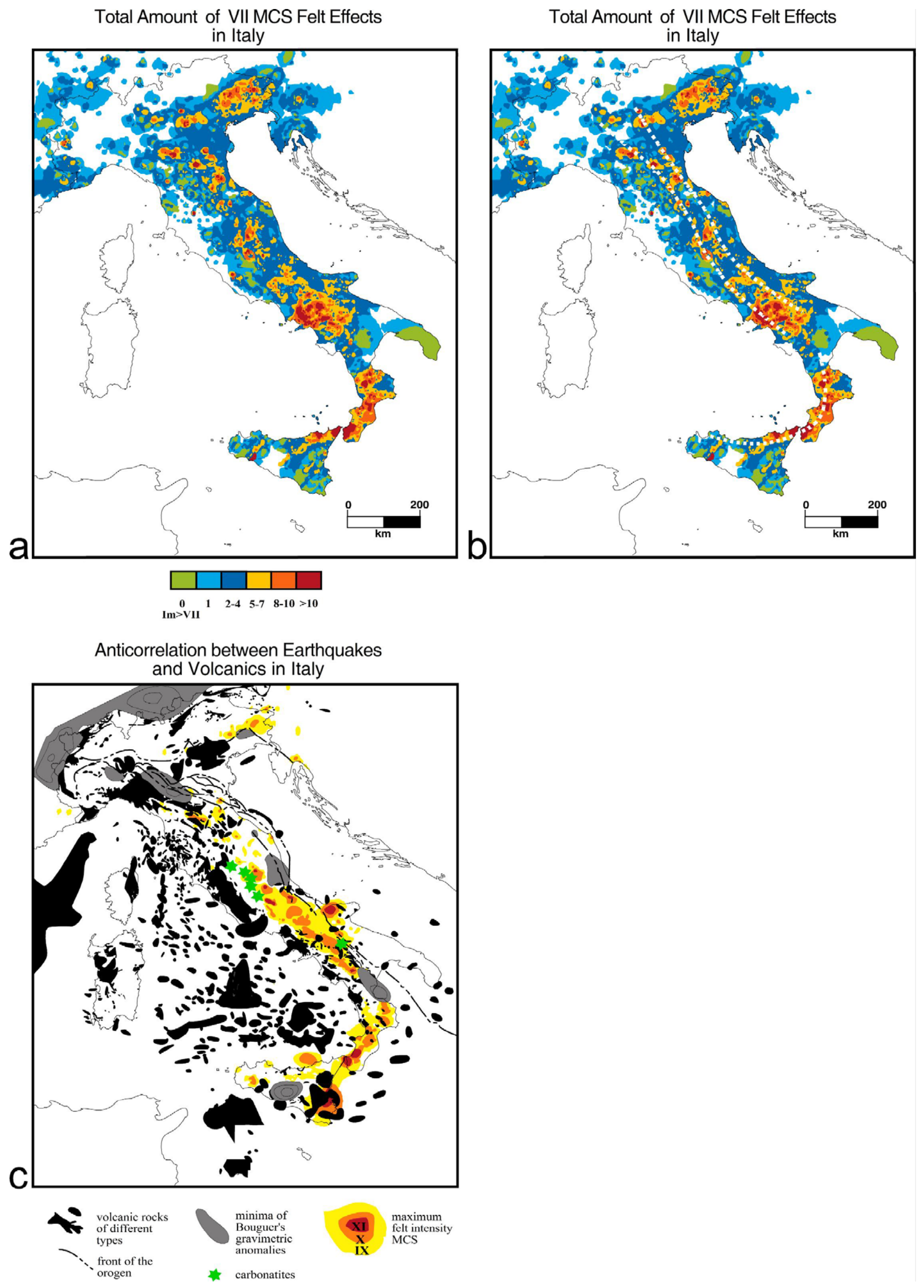

Fig. 1 - The occurrence number of felt effects VII MCS on Adria peninsula is plotted in a) and b). The elongated pattern of seismic energy emission shows twol lines (white dotted lines in b) that follows the Apennines. Possibly the two lines define a collapse zone of the orogen. In c) a comparison is shown between the higher values of the maximum felt intensity (IX, X, XI MCS degree) and all the volcanics (black areas) that are reported in "Structural Kinematic Map of Italy" (Bigi et al. CNR, 1991), in "Magnetized Intrasedimentary Bodies" (Cassano et al., Agip, 1986), and in Lavecchia and Stoppa (1996, carbonatites). The more energetic Apenninic seismicity is confined in the gaps of volcanics, and mainly immediately west from the orogen front. Recently descovered carbonatites fields (green stars) helps to better define the anticorrelation between volcanics and earthquakes. Another further factor of inhibition of seismicity is the presence of minima of the Bouguer gravimetric anomaly, which are related to greater crustal thickness or/and to different characteristics of the crust. It is possible to observe high emissions of seismic energy between two volcanic area – e.g. north of Cilento, southern Italy; on the Apennines near Bologna; on Mugello, north of Florence) – that presumably was once united. The tectonic transport operated by the earthquakes lasted several million years (Scalera, 1997). The position of high energy seismicity between already existing important volcanics distribution and the front of the orogen can mean that earthquakes are preparatory phases of new future emplacement of volcanics, and then that they are mainly related to dykes intrusions, upduction, favoured by a general tensional state of the lithosphere on an expanding Earth.

It is also evident in the different imageries – but more clear in the Montuori (2004) – that the high velocity body is spreading going in the depth, up to 350 km, and this could mean that the higher quality body connects gently with the more extended high velocity anomaly revealed by Piromallo and Morelli (2003) that extends up to 650 km under all northern Mediterranean region (Figs. 2 and 3). Also is evident from this imageries is the real continuity of the high velocity from central Apennines to Calabrian arc and further on, with the acute angle of impossible "subduction". An additional information is that while the high velocity body is continuous, the same does not subsists for the deep seismicity, which is present only under Aeolian and Calabrian arcs (up to 400-500 km), but not present under Apennines (up to 50 km). This different deepness of earthquake foci can be associated to a different degree of evolution of the tectonic process, and to the southward migration of the tectonic activity, which today produces the uplift and exposure of the crystalline basement – the Pre-Miocene substratum – of the Calabrian arc.

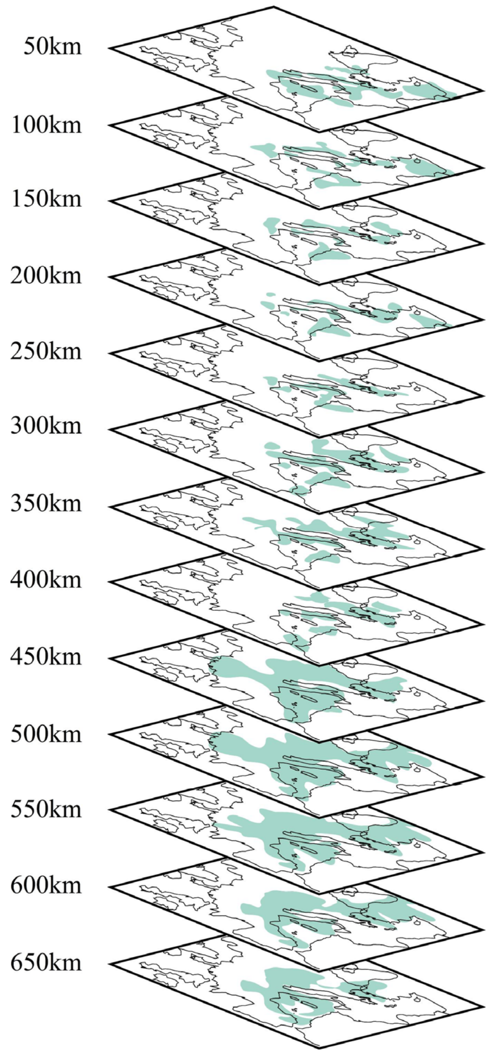

Fig. 2 - The seismic tomography (drawn on the basis of the results of Piromallo and Morelli, 2003) reveals a wide area of anomalous high velocity (light blue zones in the stack) trapped in the transition zone under the Mediterranean basin. The total area of this anomalous zone is near equal to the area of the sea basin, 3.0 x 10^6 km^2.

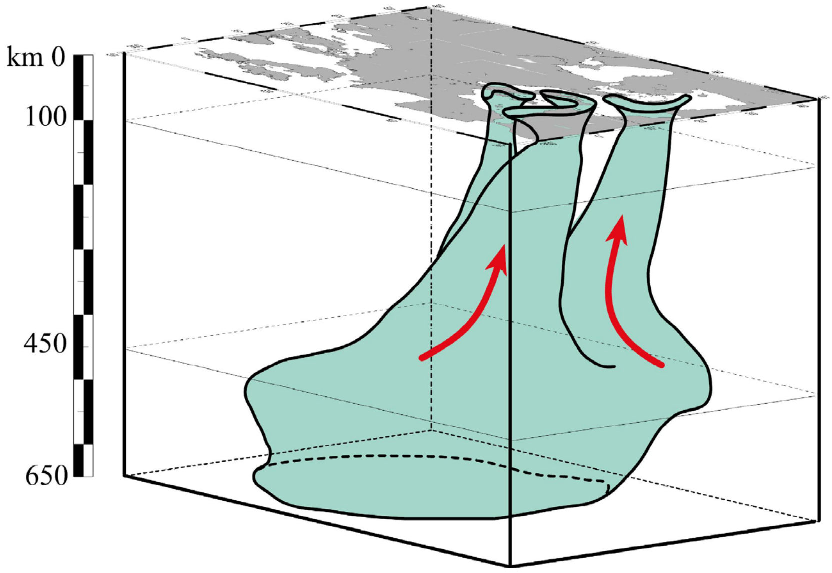

Fig. 3 - The upduction. A sketch of the non-conventional interpretation of the seismic tomographies imaging. This interpretation is based on a possible upduction of the anomalous mantle material (denser/colder than surrounding material, represented in light blue) – mostly trapped in the transition zone under the Mediterranean region – along the narrow and nearly vertical high velocity bodies revealed by body wave tomography (Cimini, 1999; Montuori 2004; and many others). Thermal and volcanic phenomena become increasingly important as the deep material approach the surface, with decompression, dehydration, differentiation and loss of fluids (Choi, 2003). Only three branches of the probably very complicated sublithospheric branching are shown. The somewhat more complex pattern of the 50-450 km density anomalies can be seen in the stack of high velocity zones in Fig. 2, which has been traced on the basis of the paper of Piromallo and Morelli (2003).

All this is evidence of stress status and direction mutually consistent among different data and methods. Passing from the surface clue of a collapsing narrow belt along the Apennines bounded by two line of more frequent VII MCS degree occurrence – supported by surface seismogeodetic observations (Salvi et al., 1997; Barchi et al., 2003; Hunstad et al., 2003; they evaluate a spreading of the belt of 2.5-5.0 mm/yr) –, to the breakouts of wells depth up to 7 km, to the focal mechanisms of earthquakes up to 20 km, to the lack of a mantle lid beneath the Apennines crust (from Pn, Sn, Lg analysis; Mele et al. 1996, 1997), to the presence of carbonatites that are signs of rising of hot mantle material (Lavecchia and Stoppa, 1996; Bell and Tilton, 2002; Lavecchia et al. 2002) under the crust in a tensional stress tectonic environment, to the indication the possibility of narrow rising (Fig. 4a), or upduction, of deep mantle material (higher density, from body wave tomography), all these information converge on the possibility that Apennines are in a state of nascent rifting. Finally, continuing the analysis with the deeper regional tomography under all the Mediterranean and bordering zones (Piromallo and Morelli, 2003), a wide zone of higher velocity (extending from 37°N to 50°N and from longitude 5°W to 45°E, with an extension nearly coincident with the 3.106 km^2 area of the Mediterranean basin) is present under the north of the basin and Adria Peninsula starting at the depth of 450 km and well defined up to 650 km – practically all the transition zone (Fig. 2). Albeit different ad hoc interpretations are possible (Piromallo and Faccenna, 2004) – but ever with cold descending materials –, this is a confirmation of a first indication of a uprising of the mantle discontinuity already found by Scalera et al. (1981a,b) using the dispersion of the seismic surface waves. Also this can be interpreted as a rising of the discontinuities as cause/consequence of the Mediterranean opening (Fig. 4,

Fig. 5). In my opinion the higher velocity zones are the images of what is actually acting in building up the tectono-orogenic phenomena we observe on the surface (Fig. 5). This mean that the direction of the main transport of mass and of different forms of energy (seismic, geochemical, volcanic, hydrothermal, …) is from below toward the surface with different prevalence of one form over the others, depending from the depth, pressure, temperature, all quantities linked to the decompression state of the rising material.

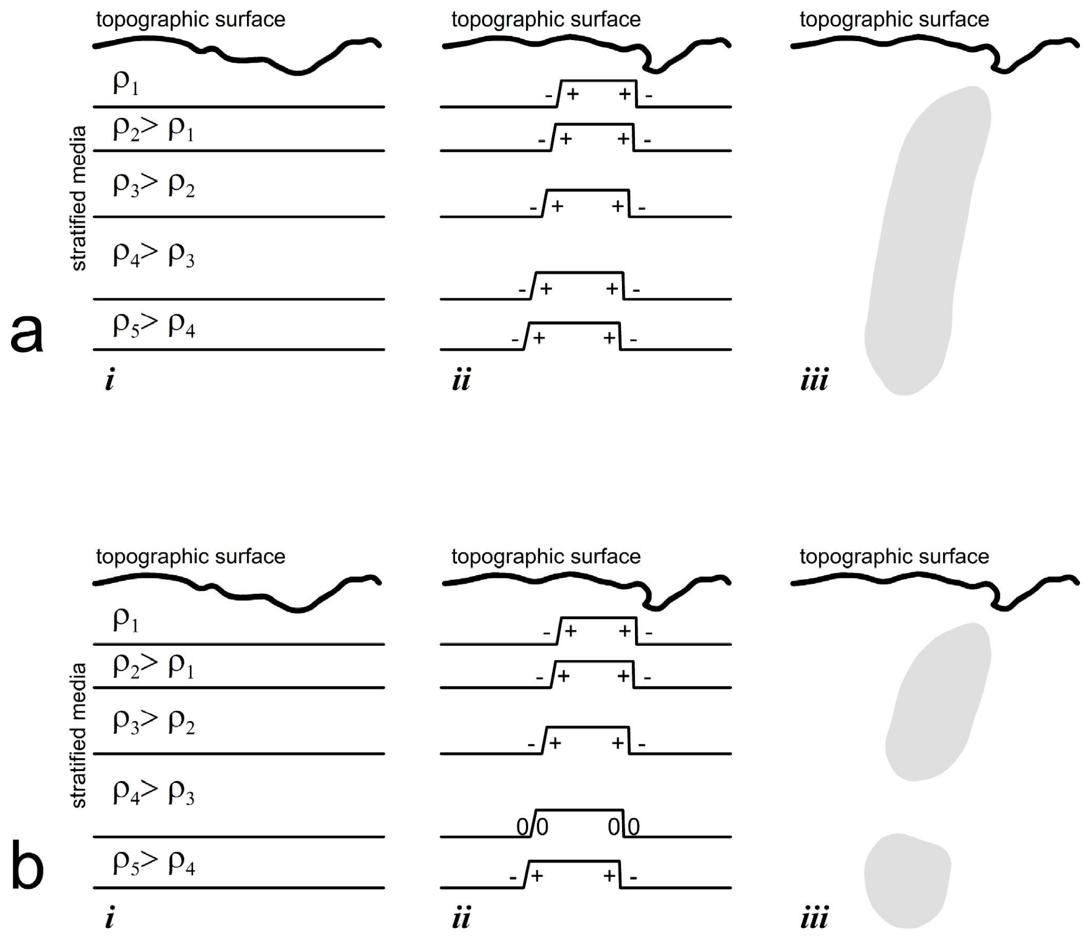

Fig. 4 - a) On an expanding Earth, the internal pressure drives the push-up of deep mantle material along elongated weakness zone. If the previously undeformed stratified media i has a density function increasing toward the Earth's centre, the rising column in ii produces a contrast of density (represented as faced – + in ii) that the seismic tomography, represented in iii, can interpret erroneously in a different way: a cold downgoing slab. b) The case can happen that, for example, in the fourth strata the rising column in ii , because of difference in decompression or depletion of fluids, reaches a state in which the resulting elastic parameters produces a null contrast of velocity (represented as faced 0 0 in ii) and consequently the slab-like continuity appears broken in the tomography represented in iii. Such situation can be erroneously interpreted as a detached slab which is dropping toward the deep mantle.

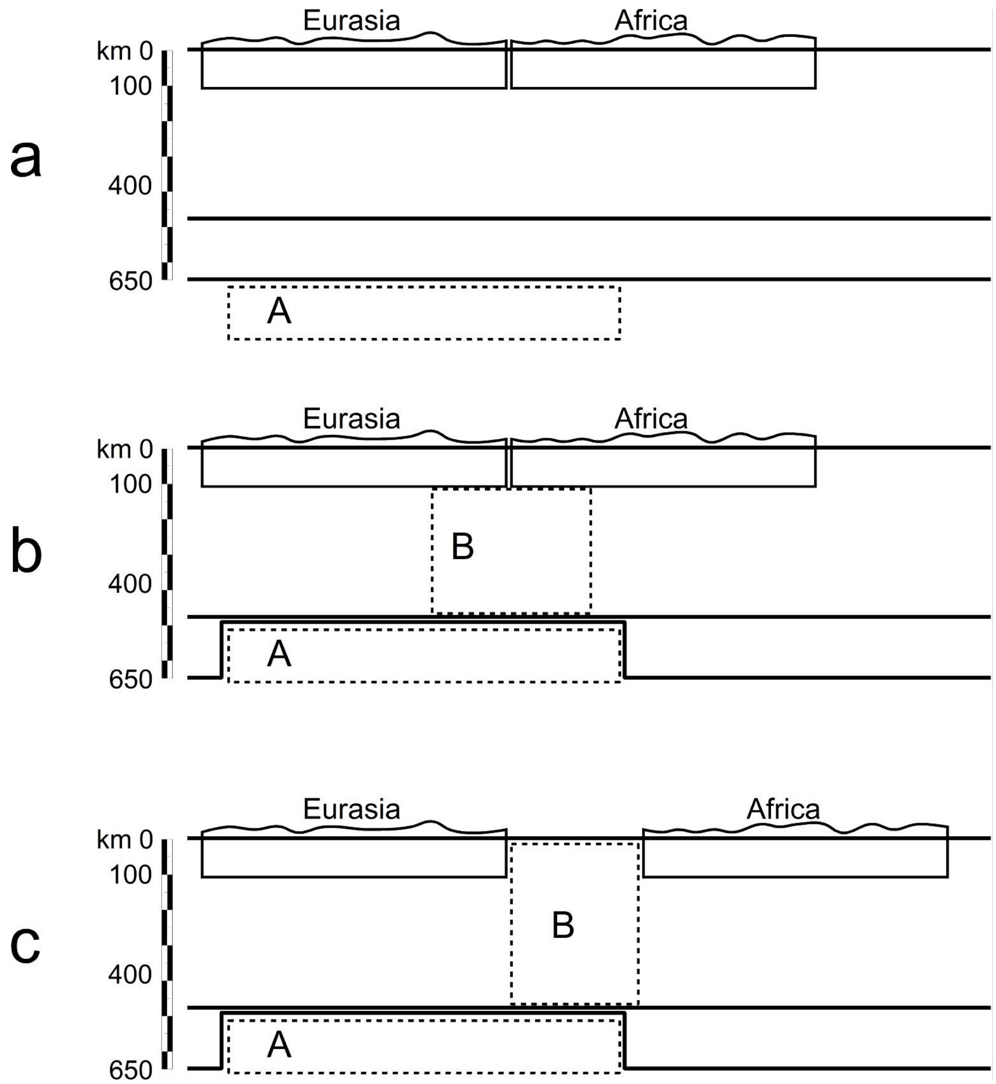

Fig. 5 - In this simplified two-dimensional graphic analysis the effect of an expanding lower mantle on the upper mantle is depicted. All the different dotted rectangles have the same area in a), b) and c). If a portion of lower-mantle material A represented in a), rises to occupy an equal volume in the zone between 410 and 650 km in b), then an equal volume of upper upper-mantle B should be accommodated under the lithosphere. The result is a stretching and final opening of the lithosphere, making place to a nascent ocean. The described situation is similar to the real observed pattern of the mantle materials under the Mediterranean area, which distribution of high-velocity zones and their cubature are compatible with the actual opening of the basin. The real evolution of the process tends to make more evident the contrast of velocity along what is called "Wadati-Benioff seismofocal zone", and this can be due to a variety of cause, one of which is the rising of more dense materials in this zone, but a concomitant one can be the dehydration and depletion of the uprising mantle proposed by Choi (2003), a process that is in accord with the observed volcanic phenomena.

DISCUSSION AND CONCLUSIONS

This mechanism of uprising can explain both the elongated and slab-like tomography-revealed structures, and the frequently found vertical interruption of their continuity (Fig. 4b) that has often lead to the interpretation of a torn off and drop down of the inferior part of the slab (see a version of these ideas on Mediterranean scale in Piromallo and Faccenna, 2004). In fact, depending from the state of temperature and decompression of the rising materials, it can happen that the same refractive and elastic parameters of the undisturbed surrounding mantle could be reached in some depth window of the slab-like region (Fig. 4b) resulting in an absence of contrast in the tomography and in a consequent false interpretation of a breach in the subducting slab.

Quantitatively the opening of the entire Mediterranean basin needs an emplacement of a volume of a new lithospheric material like a volume of a geometric ideal solid of basis $3 \cdot 10^6$ km^2 (the area of the basin) and height of approximately 100 km (the thickness of the continental lithosphere), namely a volume of $3 \cdot 10^8$ km^3. This volume is less than the amount of x h = 200 km), and then is well compatible with this mantellic source of uplifted material (Fig. 5).

The progressive displacement of the arc-trench zone with the opening of the back arc basin could be interpreted as the progressive emplacement of new differentiated materials, mostly basaltic but with relics of undifferentiated mantle materials, fragments of granites (wide sense). Some cyclic nature in the upwelling and distensional process could lead to the abandon of old regions of uprising (along the Wadati-Benioff zone, as historically envisaged by Hilgenberg in 1974) and the activation of a near new parallel region (see the model in Scalera, 1998). The progress of the process can lead to the final emplacement of a mid oceanic ridge.

The possibility to resolve in this interpretation the apparent paradox of surface tensional stress vs. deep higher quality/velocity body, can reside in a radical change in our view about the Earth's evolution, favouring an expanding Earth framework (Scalera, 2003; Scalera and Jacob, 2003).

Owing to the strict similarity of some Mediterranean tectonic situations – arcs, trenches, Wadati-Benioff zones, volcanic and seismic activities – to the East Asia ones, which are commonly interpreted as produced by plate convergence, many clues can be examined that are at variance with the hypothesized Africa-Eurasia convergence. As matter of fact, evidences for rifting prevail on those for compression and, moreover, many tectonic situations previously interpreted as due to plate convergence, are associated or mixed to rifting clues. This lead to interpret the actual Mediterranean as a phase – perhaps the last – of the slow opening of a nascent ocean, which slowness is due to his antipodal position with respect to the region of maximum sea-floor expansion rate – namely the Nazca triple point zone.

The proposal is put forward – mostly based on regional seismic tomography evidences – that an extrusion – or upduction – toward the surface of mantle material wedges coming from a widespread high velocity anomaly trapped in the transition zone could be a new work hypothesis. This new interpretation of the high velocity bodies revealed along the Mediterranean Wadati-Benioff zones deserves to be better developed and generalized to circum-Pacific arc-trench zones (Choi, 2003) in order to explain all the global and regional scale observations (Fukao et al., 2001) as due to a prevailing tensional regime.

Because on an expanding Earth the Mediterranean region has had ever a little latitudinal extension, it is possible in this view, to identify as Mediterranean phases of opening also the Paleo Tethys and Neo Tethys 'closures', which have added to the Proterozoic nuclei the Variscan and Alpine terranes respectively. The paleo-geographical evolution of the opening Mediterranean basin from Early Cretaceous to Recent (Fig. 6) can be envisaged with the drifting of each little fragment (Balearic archipelago, Sardinia, Corsica, Sicily, North and South Calabria) accompanied and favoured by the growing Africa-Europe distance. These phases – from Proterozoic to Recent – and their orogens has to be considered as extensional phases (Ollier, 2002, 2003). In this sense, considering the ongoing process of opening as having

Proterozoic origin, it is possible to speak of the Mediterranean as a slowly nascent ocean, but paradoxically of a very old ocean.

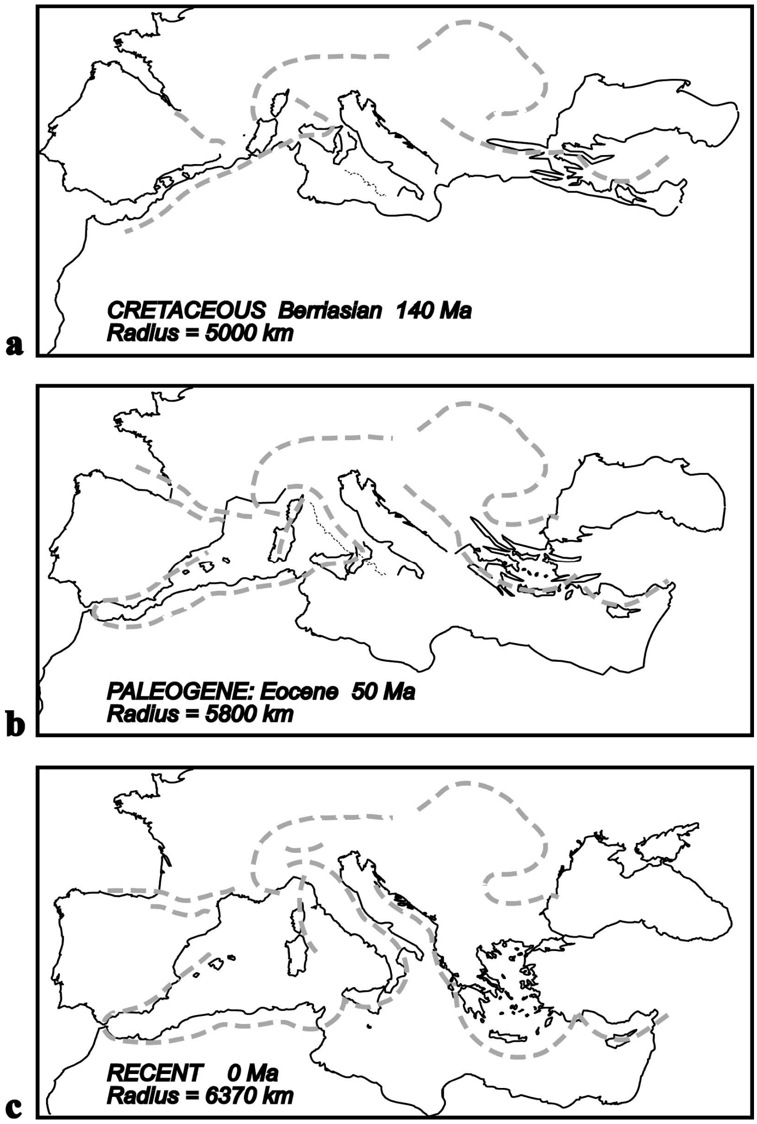

Fig. 6 - This cartoon represents the paleogeographic evolution of the Mediterranean basin. a) The Early Cretaceous reconstruction (very similar to the Triassic one in Scalera 2003): North African margin is in contact with all the fragments of the Eurasia-Africa today displaced in the centre of the basin. Sicily is placed at NW with respect to Calabria. This reconstruction does not exclude the possibility of movements and existence of shallow and narrow sea basins in Eurasia, as testified by the Alpine orogen and Carpathian arc. Also very probable is the partial existence at this time of the Black Sea basin, bounded at south by a narrower Anatolian region, which region has been enlarged by the evolution and spreading of the Anatolian orogen. b) In this intermediate time of Eocene the two fragments of Sicily and Calabria are reaching their modern mutual position after the transtensional shift of Sicily along all the Adriatic and Apulia plate margin. Only the North Tyrrhenian basin is open at this stage. c) The Messinian to Recent conversion of the motion of African plate in a westward slow drift has produced a tensional state of the Apennine nascent belt and a rapid grown and spread of the orogen over the Messinian Adriatic evaporites.

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